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Abstract

A personal computer based digital lock-in detector was developed and used in ultra-low level noise spectrum analysis. The digital lock-in detector was integrated with a digital spectrum analyzer based on an Apple IIe computer to form a complete noise spectrum analysis system. This system is capable of analyzing noise signals much lower than internal amplifier noise.

In experimental electrical noise studies and similar areas, many signals are not measurable because they are lower than the internal amplifier noise. Especially at low frequencies, amplifier noises become overwhelming, due to the $1/f$ noise generated by the internal active devices. By using lock-in detection¹, the internal amplifier noise can be rejected. Low frequency noise signals are conventionally processed digitally and the use of a digital lock-in detector results in an all-digital system.

Fig. 1 shows the spectrum analysis system using the digital lock-in detector. The major hardware support for the system is an Apple IIe personal computer and an IQS 401 spectrum analyzer card².

The modulation is done externally to the computer and it is done in the analog domain. The square wave generator is controlled by the sample and lock-in detection subroutine. The square wave generated is filtered by a low-pass filter to produce a sine function for modulation, and it is synchronized to the demodulation. The synchronization guarantees the detection to be locked-in, thus there is no problem with modulation and demodulation not being in phase.

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Since the sample rate should not be lower than the Nyquist sample rate, a digital low-pass filter is provided for obtaining data of lower sample rates for spectrum analysis. The output from the lock-in detector can be either applied directly to the spectrum analyzer or it can be filtered and resampled to get data of lower sample rates. The cut-off frequency of the digital low-pass filter is $1/8\pi$, and the resampling rate is $1/8$ of the original sample rate.

The spectrum analyzer is modified from an IQS 401 spectrum analyzer. Besides other modifications, the following two features have been added³: spectral averaging and power spectrum scaling. The spectral averaging feature reduces the standard deviation in power spectrum estimation. The number of averages can be up to 8 for 512-point FFT's. The power spectrum scaling feature normalizes the power spectra to v^2/Hz .

Performance of the system is illustrated by measuring the noise of several resistors. Fig. 2 shows the set-up. v_m is the modulating signal generated by the computer. The two $100\text{k}\Omega$'s are metal film resistors, whose $1/f$ noise is negligible. R_1 's are the ones whose noise is to be measured. R_1 's resistance is small compared to $100\text{k}\Omega$, so that the current in the loop remains approximately the same for different R_1 's.

Fig. 3 shows the noise power spectra of a $1\text{k}\Omega$ metal film resistor, a $1\text{k}\Omega$ carbon resistor and a $10\text{ k}\Omega$ carbon resistor. The original power spectrum of the internal amplifier noise is also plotted for comparison.

Since the internal amplifier noise contains components which have random phases and whose frequencies are close to the modulating frequency it produces an impulse-train output from the lock-in detector and its power spectrum is a horizontal line (see the spectrum labelled "1k metal film").

The $1/f$ noise from the $1\text{k}\Omega$ metal film resistor is negligible and

its thermal noise is lower than that of the amplifier, therefore its power spectrum is the same as that of the amplifier noise (measured by the lock-in detector).

Both the 1k Ω and the 10k Ω carbon resistor show 1/f noise. From the empirical equation⁴

$$S_V(v, f) = \frac{\alpha v^2}{N f}$$

where S_V is the power spectrum, α is a constant for the same type of material, v is the dc voltage across the resistors, f is the frequency at which the noise is measured, and N is the number of carriers engaged in conducting. In our case, v is approximately constant. When R_1 's are changed from 1k to 10k, N is reduced by a factor of 10, therefore the power spectrum should differ by an order of magnitude, which is shown by the result.

The digital lock-in detector developed here provides a highly attractive way for ultra-low level signal measurements. The results show that it is capable of detecting signals much lower than the internal amplifier noise. The lowest level which can be detected is determined by the components in the amplifier noise whose frequencies are close to the modulating frequency. The design of the detector guarantees the detection to be locked in, so correct results can be obtained. The digital method used here reduces the cost by tens of times for this kind of ultra-low level signal measurements.

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2. IQS Inc., The IQS Series 401 FFT Spectrum Analyzer for the Apple II & III Personal Computer.
3. Steven W. Smith, Rev. Sci. Instrum. 56(1), January 1985.
4. F. N. Hooge, T.G.M. Kleinpenning and L.K.J. Vandamme, Rep. Prog. Phy., 44, 479 (1981).

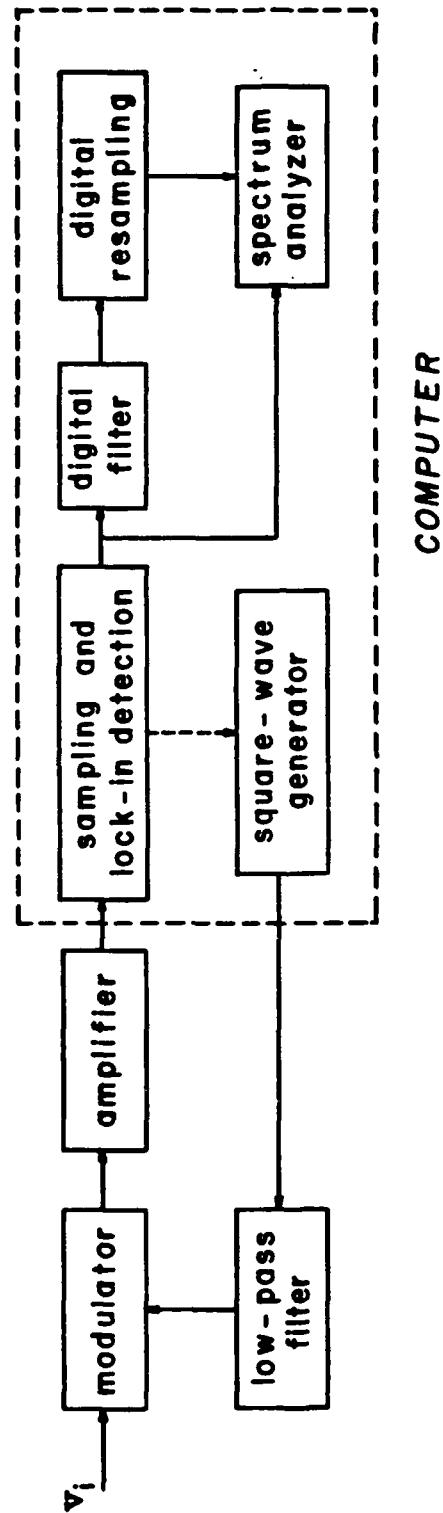


Fig. 1 Block diagram of the spectrum analysis system

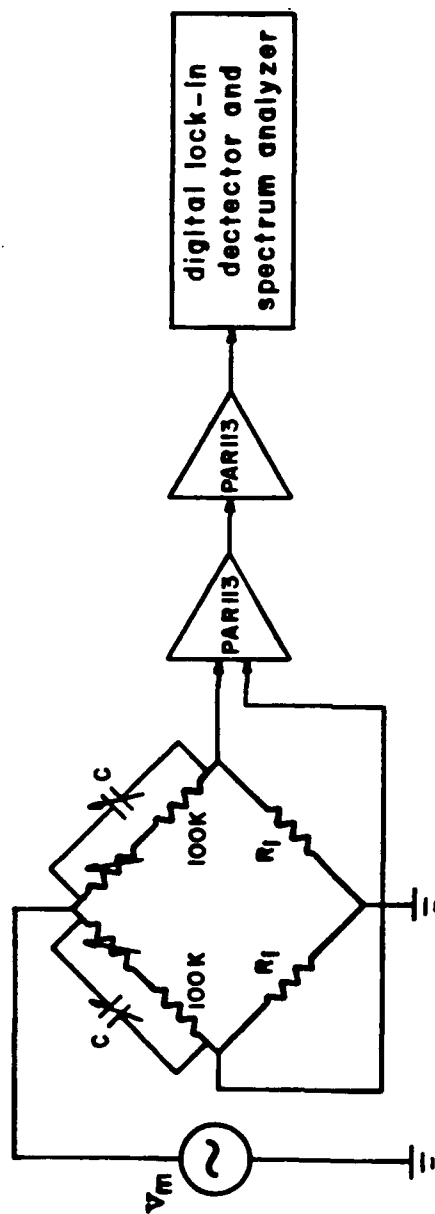


Fig. 2 Set-up for resistor noise measurement

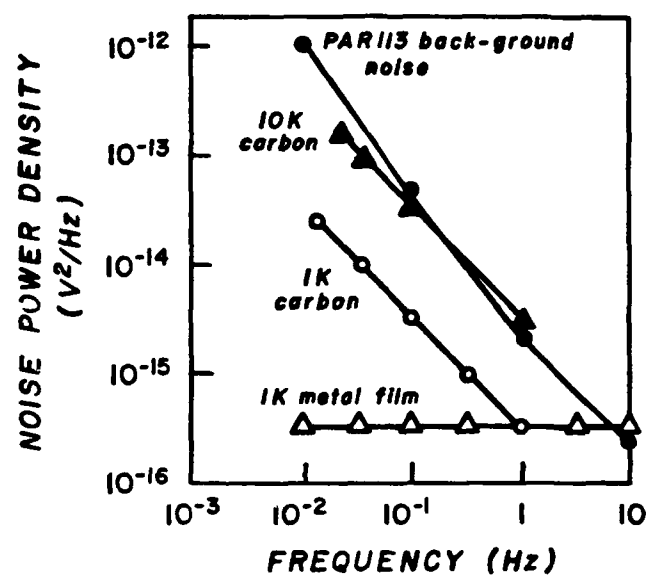


Fig. 3 Noise power spectra of resistors

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